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REPORT NO _____

**Warfighter Physiological Status Monitoring (WPSM):
Body Core Temperatures During 96 h of Swamp Phase
Ranger Training**

**U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts**

March 1997



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TECHNICAL REPORT

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**WARFIGHTER PHYSIOLOGICAL STATUS MONITORING (WPSM): BODY CORE
TEMPERATURES DURING 96 H OF SWAMP PHASE RANGER TRAINING**

by

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FOREWORD

In February 1995, four hypothermia fatalities occurred among soldiers participating in U.S. Army Ranger training at Camp James E. Rudder, Eglin AFB, Florida. This prompted the Ranger Training Brigade (RTB) to task the U.S. Army Research Institute of Environmental Medicine (USARIEM) to review the Cold Weather Immersion Limits Table for preventing hypothermia. Review and recommendation for revision of this Table, which is used to guide cold weather training at Camp Rudder, was completed early in 1996. The purpose of the present study was to confirm that core temperatures of Ranger students did not fall to unsafe levels during swamp phase training when the revised Cold Weather Immersion Limits guidelines were followed. This report presents core temperatures from ten Ranger students participating in winter swamp training at Camp Rudder, Eglin Air Force Base, Florida, during February of 1997. Unfortunately, the unusually warm weather during the study period precluded collection of the data needed to validate the Immersion Limits Table. Thus, collection of the physiologic data needed to validate the Table will resume in the winter of 1997/1998. This study provides important insights into (a) the magnitude of core temperature fluctuation of soldiers during intensive training, (b) the performance characteristics of the body core temperature monitoring system, and (c) new ways to facilitate the management and interpretation of data. This research supports the Warfighter Physiological Status Monitoring effort as well as new efforts by the Dismounted Battlespace Battlelab to provide useful physiological status information to commanders in future soldier systems.

ACKNOWLEDGEMENTS

This study would not have been possible without the support of the Ranger Training Brigade chain of command. We are particularly indebted to the Commander, Executive Officer, and Ranger Instructors of the 6th Ranger Training Battalion, Camp Rudder, Eglin AFB, Florida, for their significant professional contribution to this research effort. We also acknowledge the Ranger students who volunteered to participate in this study. All these soldiers showed an exemplary interest in the welfare of future Ranger students.

EXECUTIVE SUMMARY

In February 1997, ten Ranger students were studied during four days of swamp phase training at Camp Rudder. Objective: to confirm that core temperatures during swamp movements remain above 35.5°C (95.9°F) when the Ranger Cold Weather Immersion Limits Table guidelines were followed. Methods: an accurate, unobtrusive, lightweight (3 oz) Body Core Temperature Monitor (BCTM) and an FDA-approved temperature pill were used to continuously measure and record core temperatures during 96 hours of field training. A logbook of date, time, grid coordinates, water temperature at the debarkation point, and immersion depth was kept. Weather data, including river depth and water temperature, was obtained from automated weather stations in the Ranger training area. Results: Due to the unusually warm weather conditions (air temp. = 56 to 76°F) and limited immersion time, the data needed to validate the Immersion Limits Table could not be collected. Nevertheless, the volunteers exhibited a remarkably wide range of core temperatures. Average core temperature ranged from 35.9°C (96.6°F) to 38.2°C (100.8°F), with individual values ranging from 35.4°C (95.7°F) to 39.1°C (102.4°F). Recommendations: (a) return to Camp Rudder next winter to continue effort to validate Cold Weather Immersion Limits Table, (b) initiate similar studies of Mountain Phase of Ranger Training, (c) define design of an improved BCTM capable of transmitting core temperature data to a data collecting system that would warn when a soldier's temperature was outside safe limits.

INTRODUCTION

In response to a request in April 1995 from the Ranger Training Brigade (RTB), the U.S. Army Research Institute of Environmental Medicine (USARIEM) evaluated and revised the Cold Weather Immersion Limits Table used by the RTB to limit the amount of time Ranger students can be immersed at various depths (ankle, knee, waist, neck) and water temperatures. These revisions were based upon laboratory research and mathematical modeling. The revised Table is based on predictions of the amount of time that soldiers can be exposed to a given water temperature and depth without incurring a core temperature of 35.5°C or less. The purpose of the present field study at Camp Rudder was to initiate data collection to confirm that core temperatures of Ranger students during swamp phase training remain above 35.5°C when Immersion Table guidelines were followed.

METHODS

On 21 February 1997, the Ranger students in Class 3-97 at Camp Rudder, Eglin Air Force Base, Florida, were briefed regarding the proposed research study. The fact that participation in the study was voluntary was emphasized and the Ranger students were encouraged to ask questions. The volunteers who participated in this study gave their free and informed consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research. About half of the class was interested in participating in the study. From this group, fifteen volunteers from Charlie Company were selected (ten test subjects and five backup subjects).

Each of the fifteen test volunteers read and signed the Volunteer Agreement Affidavit after all their questions had been answered. The age, height, body weight, and body fat % of each volunteer was determined. Percent body fat was calculated from skinfolds thicknesses using standard methods (Durnin and Womersley, 1974). The total weight of each volunteer, including the weight all clothing and equipment carried, was also determined.

Body core temperatures of the volunteers were measured using a telemetry temperature pill system described below. Core temperatures were measured continuously over a 96 h period on training Days 12 through 15 (26 Feb to 1 Mar 1997) when cold weather and training involving immersion were anticipated. On training Day 12, the four member USARIEM research team went to the field training sites with the "inwalker" Ranger Instructors. After ensuring that each test volunteer had swallowed a temperature pill and had a Body Core Temperature Monitors (BCTM) attached to their Load Bearing Equipment harness, the research team returned to Camp Rudder with the "outwalker" Ranger Instructors. On training Days 14 and 15 a similar rendezvous routine was used to check that each volunteer's BCTM was receiving a signal from a temperature pill. On the morning of training Day 16 the BCTMs were retrieved. In addition, on training Days 12 through 15, the Camp Rudder Tactical Operations Center (TOC) maintained a logbook of date, time, grid coordinates, water temperature at debarkation, and immersion depths (ankle-knee-waist-chest-neck).

Body Core Temperature Monitoring.

The core temperatures of the study volunteers were measured by a telemetry temperature pill system. This approach, in use for over a decade, provides a valid measure of core temperature without the discomfort and inconvenience of a rectal or esophageal probe. Each test volunteer swallowed a standard FDA-approved ingested temperature telemetry pill (7/8" X 7/16") (CorTemp™, Human Technologies Inc., St. Petersburg, Florida) and wore a small (3.5" X 2.25" X 1"), lightweight (3.2 oz) USARIEM Body Core Temperature Monitor (BCTM). The temperature pill emits a 260 kHz signal that varies with temperature. This signal is received, recorded, and stored by the BCTM for subsequent retrieval and analysis.

Although no single definitive core temperature exists because of temperature differences among sites in the body (Sawka et al., 1996), core temperatures measured at the esophagus, rectum, and gastrointestinal tract are considered the most scientifically legitimate representation. A close relationship among body core

temperatures measured by esophageal probe, and rectal probe, and telemetry pill has been shown during exercise in temperate and hot conditions (Fox et al., 1961; Kolka et al., 1993; Sparling et al., 1993) as well as during cold conditions at rest and during exercise (O'Brien et al., 1997).

Weather data collection

Three specialized automated weather stations installed by the Rangers along a 13 km section of the Yellow and Weaver Rivers were accessed via cell phone modem every two hours and the data were recorded manually. In addition to the standard weather sensors (air temperature, wind speed, solar load, relative humidity), these stations have a river depth sensor and a water temperature sensor. The water temperature sensor is immersed at 0.3 meters below the extreme low water level, thus the depth measurement varies with river flood level. A fully automated data communications link with these stations should be completed by mid-1997.

The MERCURY system at Camp Rudder is described in Appendix A. MERCURY integrates human thermal strain prediction models with automated real-time weather and terrain information resources to predict scenario-dependent exposure limits in hot or cold environments and during cold water immersion. Physiological data from this study will be used to evaluate the accuracy of MERCURY's predictive models.

RESULTS

The average age, physical characteristics and the total load weight carried by the ten Ranger student volunteers is shown in Table 1.

Table 1. Ranger student volunteer characteristics (10 volunteers)

	Age (yr)	Height (in)	Weight (lbs)	Body Fat (%)	Load (Lbs)
Mean	24	71	172	13	97
SD	3	2	15	4	5

Range	20 to 30	68 to 76	159 to 199	8 to 18	90 to 104
N = 10; SD = Standard deviation					

Geolocation

The grid coordinates of the Ranger student volunteers during training Days 12 to 15 are listed in Appendix B and shown on the Ranger Training Area Map (Fig. 1). The volunteers moved in excess of 20 km during the 96 h study period. The Ranger training during these four days consisted of simulated combat involving raids, ambushes, boat movements, swamp movements, patrols, etc..

Weather and core temperature data

Historical data used to plan this study indicated that air and water temperatures of about 7°C (45°F) and 13°C (55°F), respectively, could be expected. The weather data and the corresponding core body temperature data for training Days 12 to 15 are shown in the figures labeled Weather (Figs 2, 4, 6, and 8 for Days 12 to 15, respectively) and average core temperature (Figs. 3, 5, 7, and 9 for Days 12 to 15, respectively).

Table 2. Air and water temperature ranges for training Days 12 to 15.

	Air Temperature (°F)	Water Temperature (°F)
Day 12	56 to 70	56 to 63
Day 13	68 to 78	60 to 66
Day 14	67 to 74	64 to 68
Day 15	68-76	64 to 68

The weather data plots show relative humidity, air temperature, water temperature, and solar radiation. Wind speed was near zero. During the four study days, relative humidity was near 100% and air temperatures were unusually high.

Cloud cover limited solar radiation on training Day 14.

The plots of average core temperature show both the average and the range (minima and maxima) of core temperatures for the Ranger students during the four study days. The plots of average core temperature also include numbers corresponding to the Ranger Training Area map and the list of waypoints in Appendix B. Ranger student immersion was limited to about 70 minutes on training Day 12 (Figure 3) and for about 60 min on Day 15 (Fig. 9). Scheduled immersion training was cancelled when heavy fog prevented the medical evacuation helicopters from flying, as required by the Camp Rudder standard operating procedures.

DISCUSSION

The compact, lightweight BCTM/temperature pill system was able to collect core temperature data with little or no impact on training. A circadian pattern in core temperature was evident, with higher core temperatures during the day and lower temperatures at night. Core temperature nadirs generally corresponded to times the Ranger students were in their patrol bases.

Due to the unusually warm weather conditions, and cancellation of the majority of training involving immersion, the data needed to validate the Immersion Limits Table could not be collected. Ranger student water immersion training was limited to training Days 12 and 15. The transient decrease in core temperature on Day 12 at about 1500 h appeared to be associated with knee/waist deep immersion in 58°F water for about 70 min.

Even with moderate weather conditions, a remarkably wide range of core temperatures were evident. Mean core temperature ranged from 35.9°C (96.6°F) to 38.2°C (100.8°F), with individual values ranging from 35.4°C (95.7°F) to 39.1°C (102.4°F). Further collection of this type of physiologic data should lead to better predictive models and better risk management for the individual soldier exposed to extreme environmental conditions.

RECOMMENDATIONS

- Resume collection of the physiologic data needed to validate the Cold Weather Immersion Limits Table in the winter of 1997/1998.
- Develop and test an "exposure table" for air similar in philosophy to the Immersion Limits Table. This new table could be used in all phases of Ranger training.
- Initiate effort to use weather and physiologic status monitoring capabilities to study Ranger students participating in Mountain Phase of Ranger Training.
- Define the design and performance characteristics of the next generation BCTM capable of transmitting core temperature data to a data collecting system that would analyze it and provide warning when a soldier's temperature drops to a certain level.

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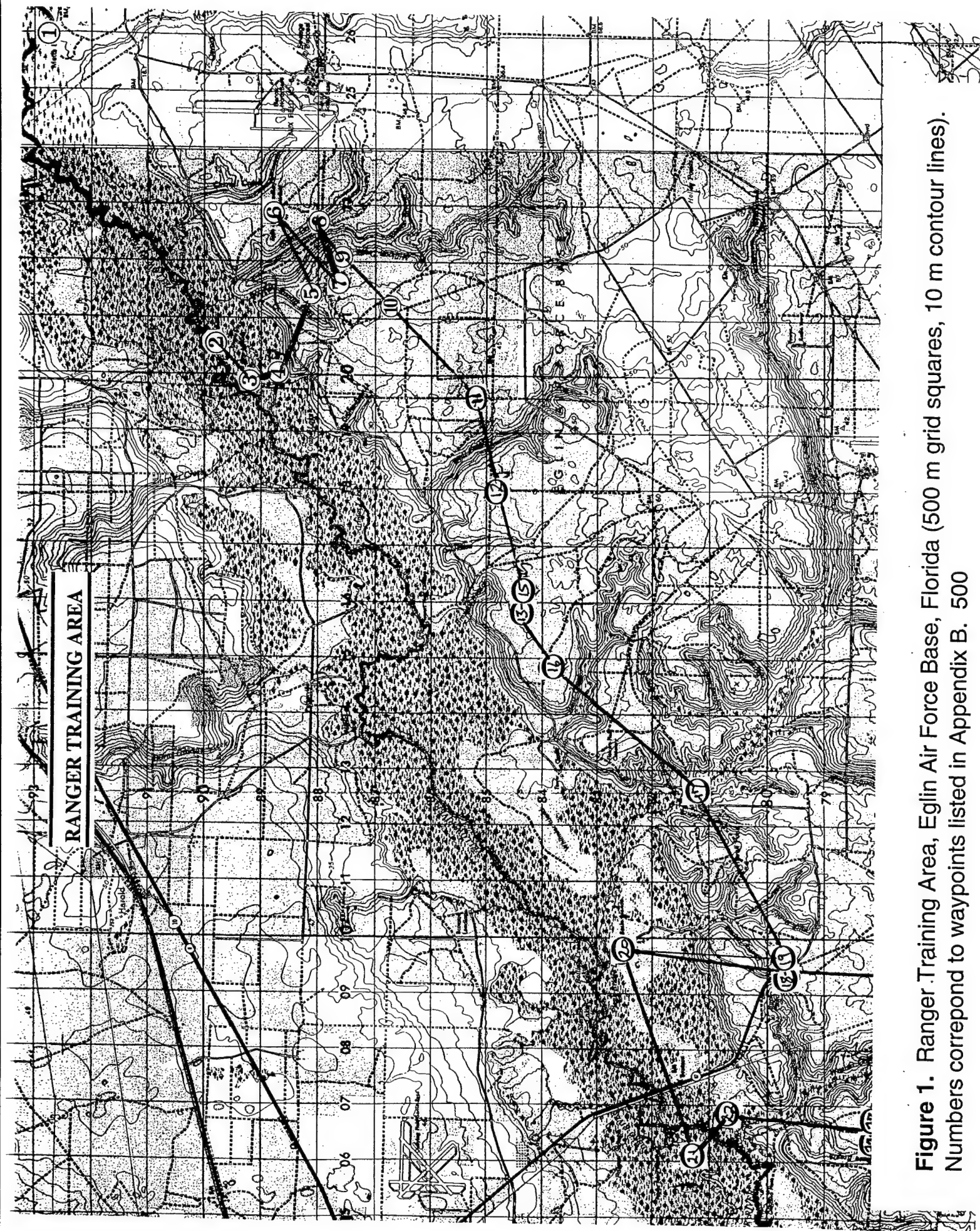
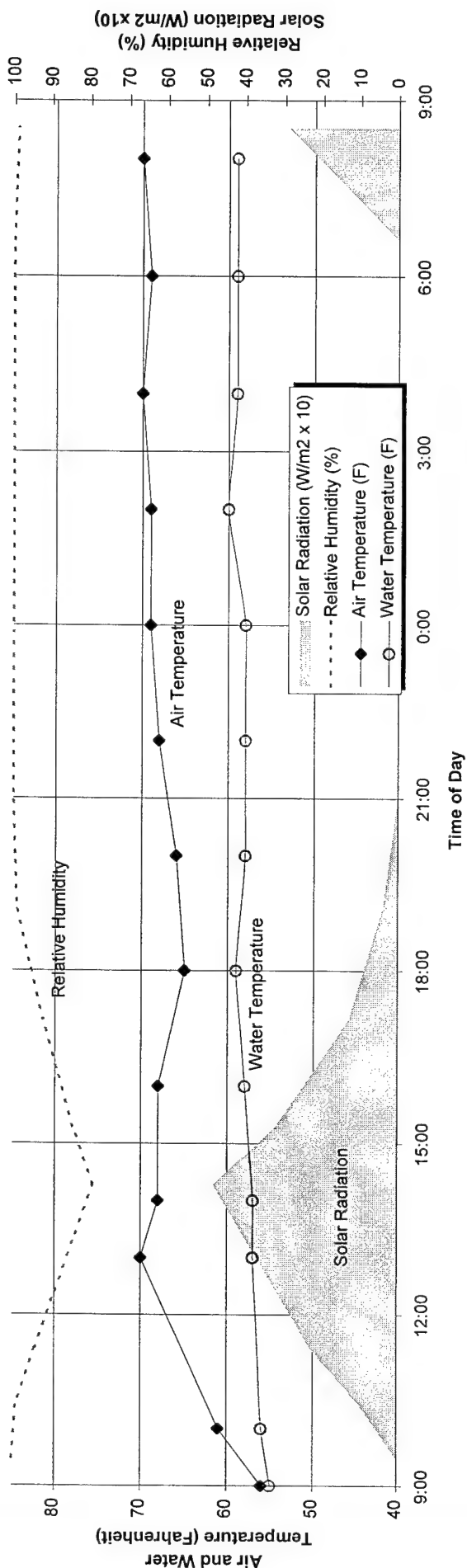


Figure 1. Ranger Training Area, Eglin Air Force Base, Florida (500 m grid squares, 10 m contour lines). Numbers correspond to waypoints listed in Appendix B. 500

Weather



Core Body Temperatures

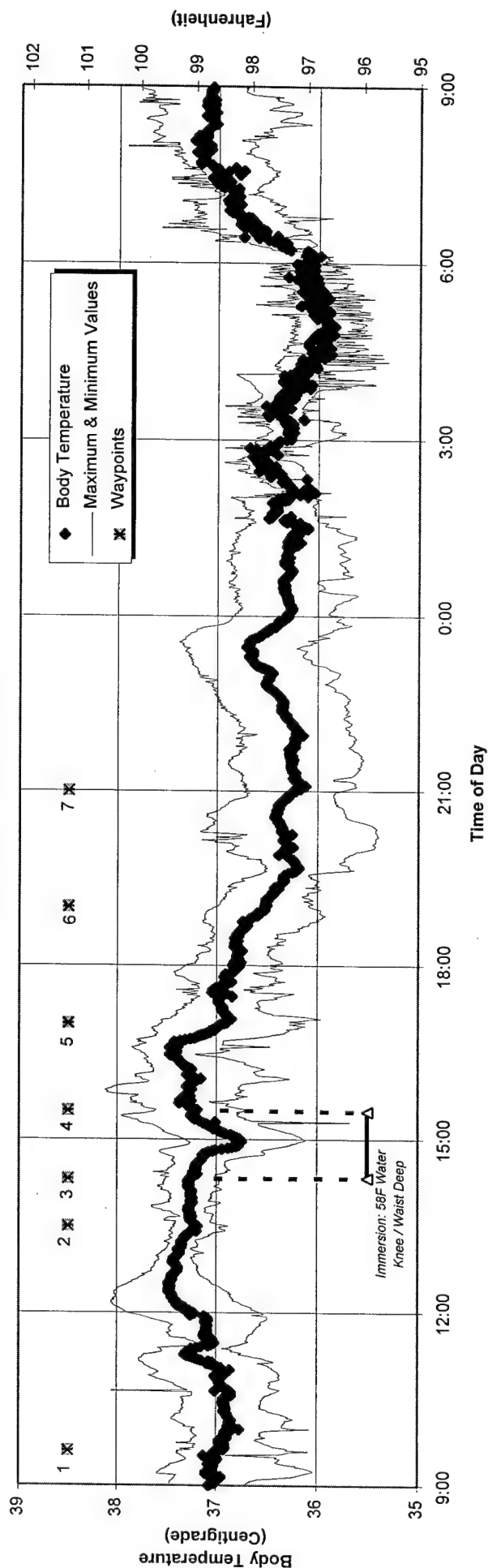
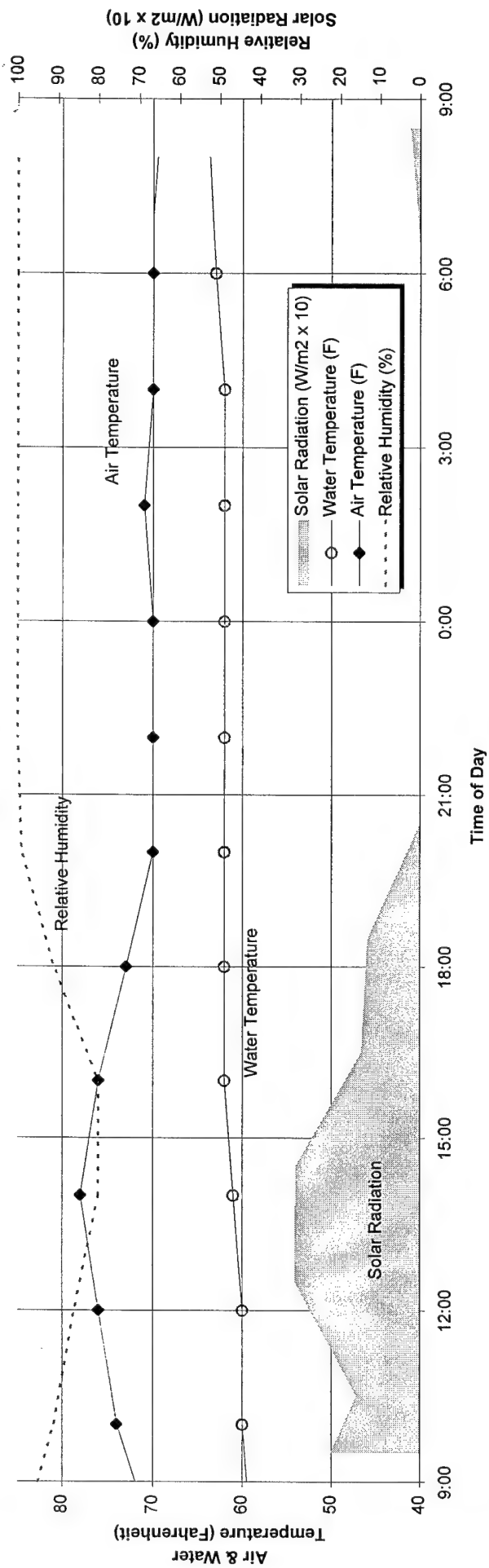


Figure 2: Weather and Core Body Temperatures (Average, Max. and Min.) for Day 12

Weather



Core Body Temperatures

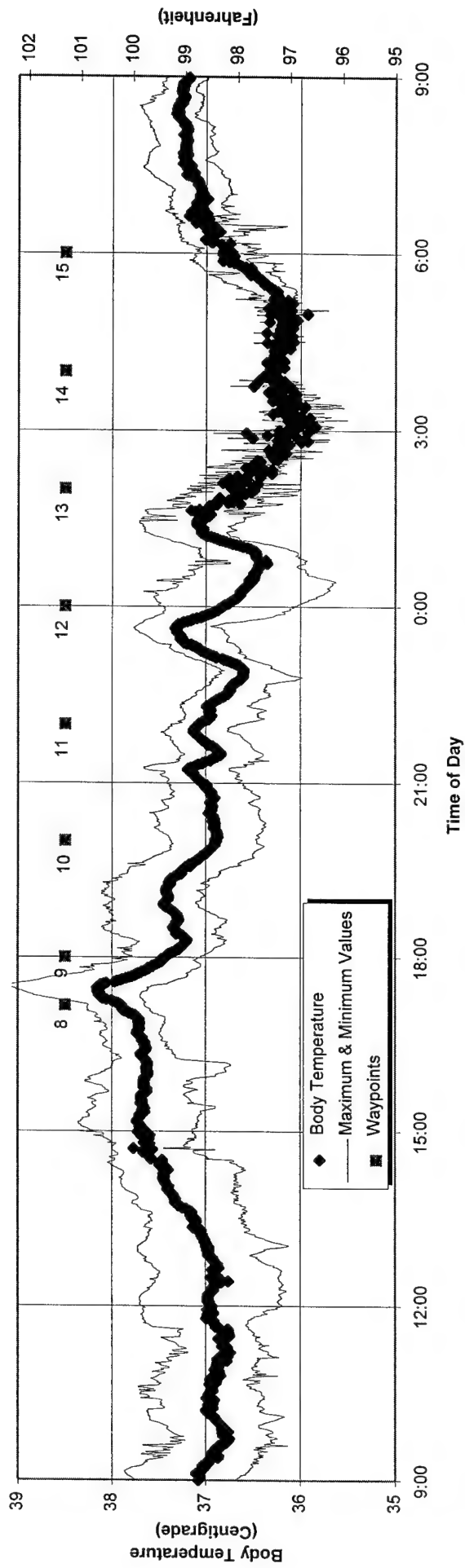
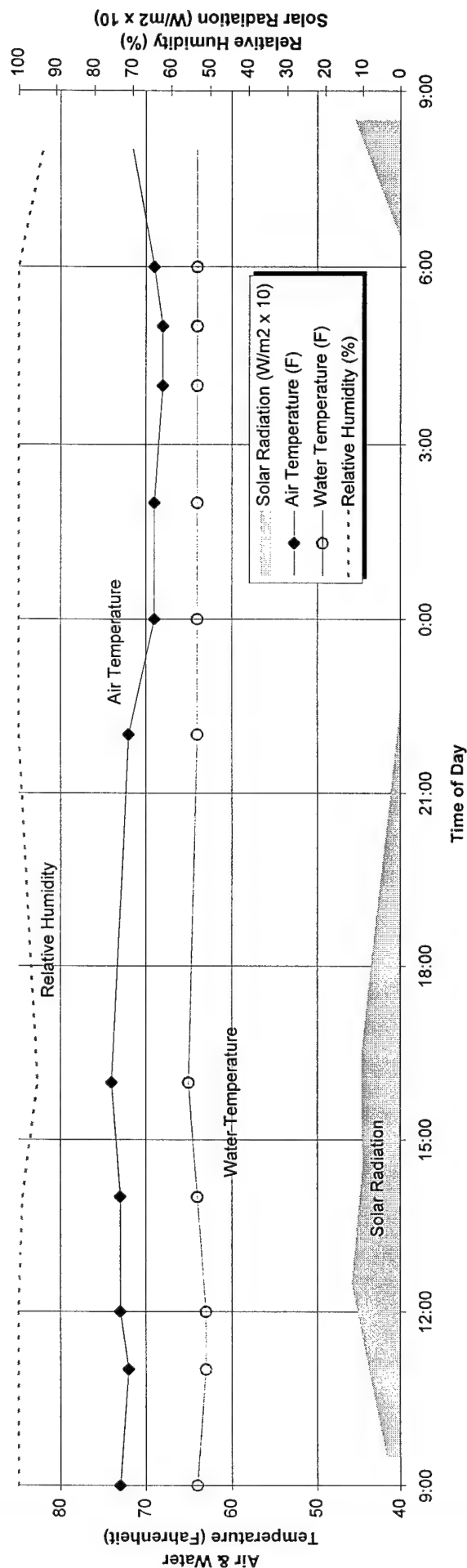


Figure 3: Weather and Core Body Temperatures (Average, Max. and Min.) for Day 13

Weather



Core Body Temperatures

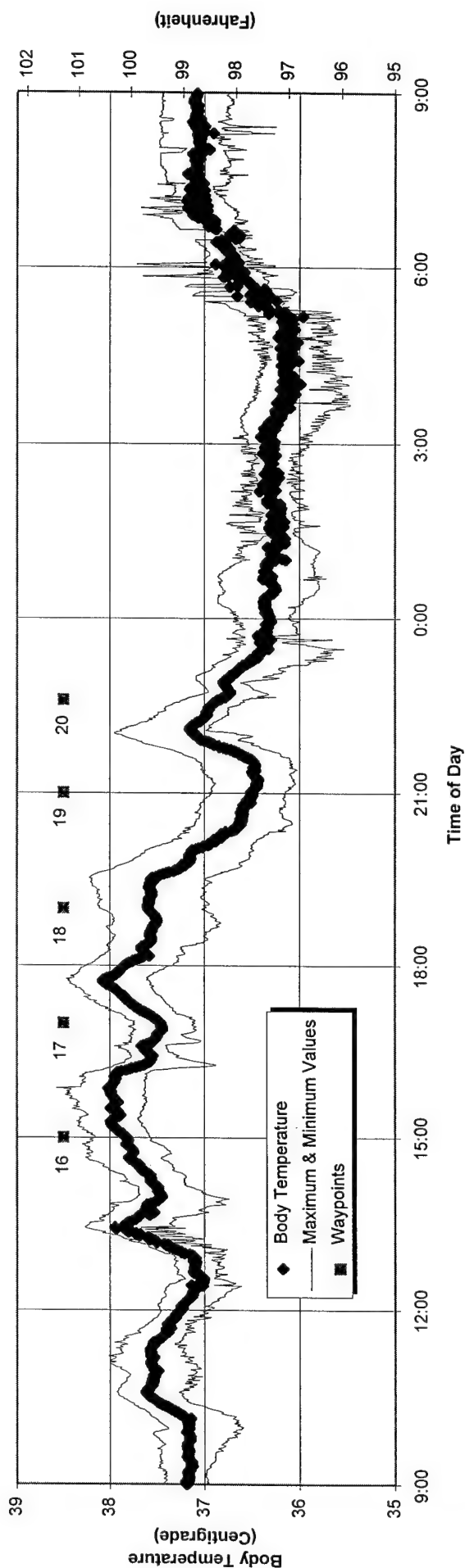
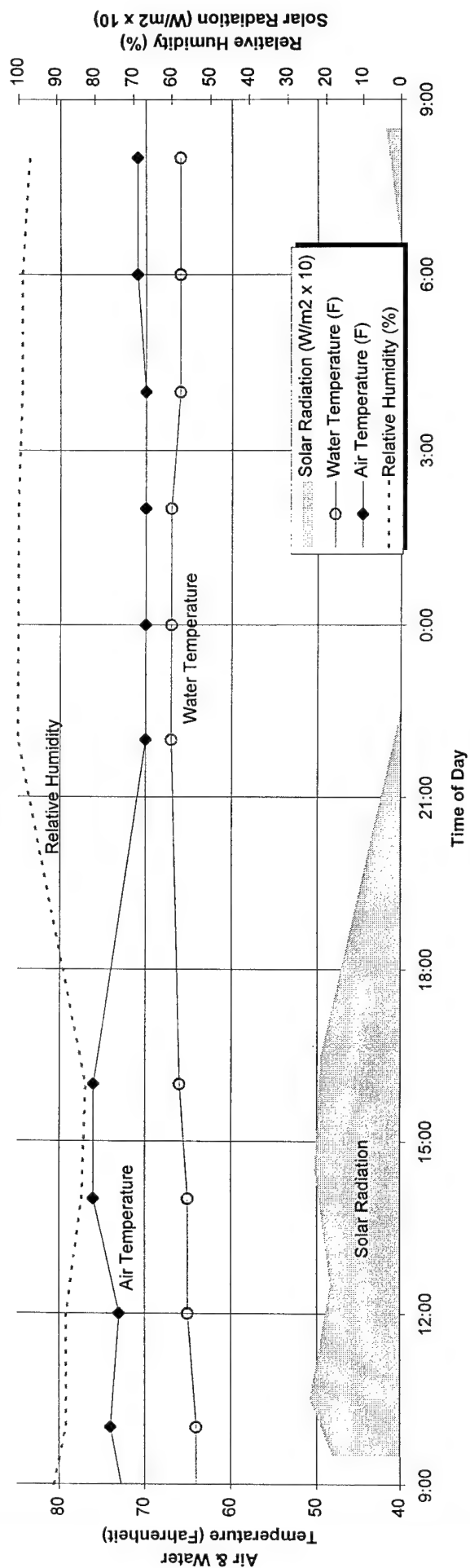


Figure 4: Weather and Core Body Temperatures (Average, Max. and Min.) for Day 14

Weather



Core Body Temperatures

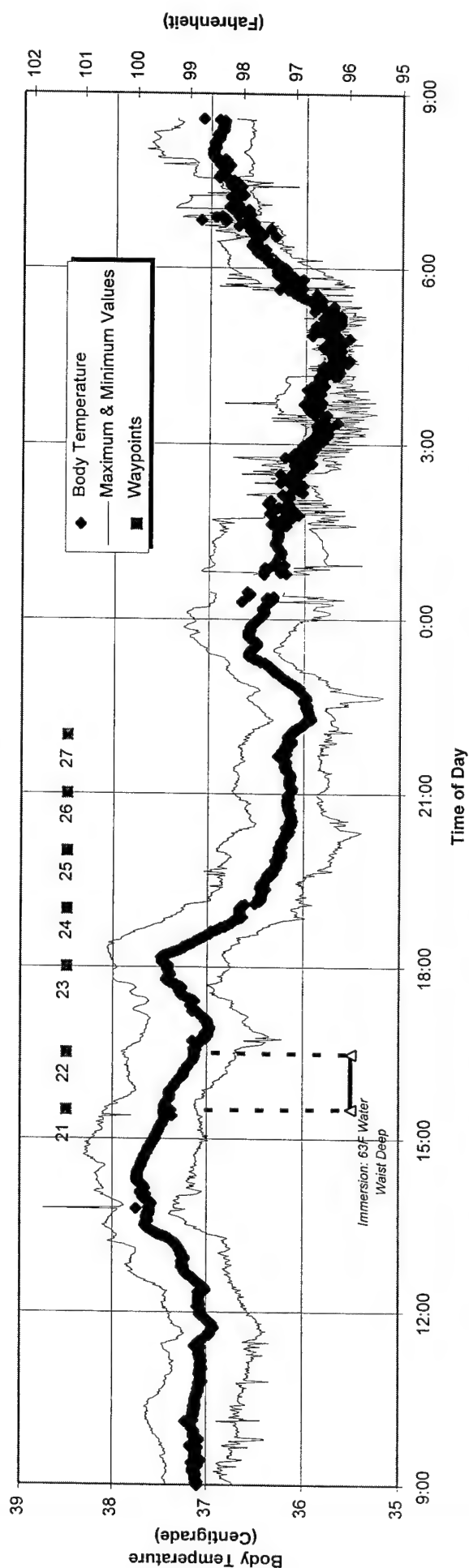


Figure 5: Weather and Core Body Temperatures (Average, Max. and Min.) for Day 15

APPENDIX A

Description of MERCURY system

MERCURY integrates a suite of human thermal strain prediction models with automated real-time weather and terrain information resources. Current models predict scenario-dependent exposure limits in hot or cold environments and during cold water immersion. In June 1996 a test bed system was installed at the U.S. Army Ranger training facilities at Camp Rudder, Eglin Air Force Base, Florida. The MERCURY-Ranger Test Bed system uses the existing network resources and automated weather data acquisition infrastructure at Eglin to obtain required predictive model inputs such as air temperature, humidity, wind speed, solar radiation and, in the near future for the cold immersion model, water temperature and depth. Using standard Internet connections between MERCURY and Eglin's Range Automated Weather Stations (RAWS) base station computer, weather data from seven to ten RAWS stations are automatically ingested at hourly intervals. These geo-located weather data sets are then interpolated in the context of Digital Topographic Elevation Data (DTED) to provide gridded weather information at 1 km spatial resolution across a 100 by 100 kilometer Eglin area window. Individual weather parameters or predictive model outputs are then displayed over a DTED greyscale image as simple color-coded overlay products. The test bed is used to validate methods needed to extend this capability to operational settings.

Key Features of the MERCURY - Ranger Test Bed (as of 01/24/97)

- * Automatic hourly update of weather information from 7 stations in the Eglin region
- * Automatic spreading of weather data across the 100 X 100 km Eglin area using objective and heuristic methods
- * Display of derived weather data for any location in the Eglin field by point and click
- * Display of individual weather station data by point and click on station icon
- * Automatic archiving/indexing of all weather data with point and click access/analysis
- * Automatic logging of communications faults/errors
- * Area zoom

- * Point and click geolocation in Latitude/Longitude or UTM coordinates
- * Point and click color hard copy production on color laserjet printer
- * Point and click selection of physiological models:

Description of MERCURY system (cont.)

Heat Strain

- * *User Input:* Height, Weight, Acclimatization Days, Hydration status (5 Categories), Work Load (4 Categories), Clothing Type (5 categories)
- * *Output:* DTED Color Overlays of Casualty Risk, Optimal Work/Rest Cycle Time, Maximum Safe Work Time, Hourly Drinking Water Requirements

Cold Survival Time

- * *User Input:* Height, Weight, Body Fat, Clothing Insulation, Mission Time
- * *Output:* DTED Color Overlay of Survival Time (Time to $T_{re}=30.0^{\circ}\text{C}$)

Cold Immersion

- * *User Input:* Height, Weight, Body Fat, Age, Metabolic Reserve, Mission Time, Walking Speed, Total Load, Terrain Type and Grade, Clothing Type, Wetness of Non-Immersed Clothing
- * *Output:* River Sensor Location Color Coded Icon (Based on Mission Duration and Predicted Time to $T_{re}=35.5^{\circ}\text{C}$)

The current suite of physiological models in MERCURY employs the following common risk representation color codes for the categorized output: Green = Low Risk, Amber = Moderate Risk, Red = High Risk

APPENDIX B. Charlie Company tracking point on training days 12 to 15 (26 Feb to 1 Mar 1997), Camp Rudder, Florida. Each 24 h day is defined as 0900 to 0900h. The tracking points correspond to those in the Body Temperature Figures.

TRAINING DAY/DATE	TRACKING POINT	TIME	GRID COORDINATES
Day 12 (26 Feb 97)	1	0936	EJ 261927
	2	1330	EJ 204897
	3	1419	EJ 198893
	4	1530	EJ 200887
	5	1700	EJ 215881
	6	1900	EJ 229888
	7	2100	EJ 218879
Day 13 (27 Feb 97)	8	1710	EJ 217879
	9	1800	EJ 220876
	10	2000	EJ 212867
	11	2200	EJ 196852
	12	2400	EJ 180849
	13	0200	EJ 160844
	14	0400	EJ 160844
	15	0600	EJ 160844
Day 14 (28 Feb 97)	16	1500	EJ 148839
	17	1700	EJ 126813
	18	1900	EJ 094797
	19	2100	EJ 094797
	20	2235	EJ 097824
Day 15 (1 Mar 97)	21	1530	EJ 062812
	22	1630	EJ 069809
	23	1800	EJ 065782
	24	1900	EJ 065782
	25	2000	EJ 065782
	26	2100	EJ 065782
	27	2200	EJ 06578

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